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## Monitoring and Analysis of Occupational Exposure to Chain Saw Exhausts

The extent of inhalation exposure to loggers from two-stroke chain saws was measured and evaluated under various conditions. Carbon monoxide, measured by personal air monitoring and determination of carboxyhemoglobin levels of the loggers, was used as an indicator of exhaust exposure. Video recordings were made to analyze the influence of varying working conditions and the individual handling of the chain saw on the amount of pollutants inhaled. The American Conference of Governmental Industrial Hygienists biological exposure index (BEI) for carboxyhemoglobin (3.5%) was exceeded during logging in heavy timber stands. When workers were paid on a piecework basis, carboxyhemoglobinemia increased to its maximum level in the first 2-3 hours of the shift and then declined. After 8 hours carboxyhemoglobin levels were 20-30% lower compared with the maximum. Increased exhaust inhalation with short-term exposures to carbon monoxide up to 400 ppm was observed in the following conditions: (1) felling operations, (2) other operations performed in a leaning or squatting position, (3) limbing in thick tops of coniferous trees, (4) working at low wind velocity, and (5) working in thick forest stands. Maximum allowable blood concentrations for carboxyhemoglobin are exceeded in chain saw operators in logging operations. Blood sampling at the end of the workday is not always suitable for determining the highest carboxyhemoglobin levels in loggers during the shift. The exposure of chain saw operators to exhaust increases under certain conditions.

**Keywords:** biological monitoring, carbon monoxide, carboxyhemoglobin, chain saw operator, chronic heart disease, video recordings

**M**odern logging methods have increased efficiency in the forestry industry and influenced working conditions of chain saw operators. **T**he use of two-stroke chain saws in logging operations for **50% and more of the work shift** is not unusual. The cardiocirculatory strain of the loggers is found to be close to the maximum continuous performance level<sup>(1,2)</sup> and even well above it in operations in mountainous terrain.<sup>(3)</sup> **T**he oxygen consumption of the loggers amounts to about 50% of the maximum oxygen uptake;<sup>4</sup> the elevated alveolar ventilation leads to increased exhaust inhalation.

The two-stroke chain saw exhaust contains the following toxic combustion compounds:

5-10% carbon monoxide (**CO**), **25%** hydrocarbons (**HC**), **0.5%** nitrogen oxides (**NO<sub>x</sub>**), and 0.5% aldehydes.<sup>(5)</sup> As much as **30%** of the fuel-air mixture remains unburned and is emitted as exhaust, which leads to **HC** emissions much higher than in four-stroke engines. However, **NO<sub>x</sub>** emissions are **30** times lower than in four-stroke spark-ignition engines. Altering the fuel-air mixture changes the amounts of harmful substances emitted.<sup>6,7</sup>

Measuring **CO** levels is an effective way of gauging exhaust exposure, as **CO** is the main toxic compound emitted by two-stroke chain saws. After inhalation **CO** is bound as carboxyhemoglobin (**COHb**) and carboxymyoglobin, from

which it is not easily released. CO has an affinity for hemoglobin approximately 240 times greater than oxygen and an affinity for myoglobin that is 20 times greater. In mitochondria, CO leads to blocking of cytochrome- $a_3$ -oxidase.<sup>(6,7)</sup> CO reduces the cardiac threshold for ventricular fibrillation during myocardial ischemia.<sup>(8)</sup>

In a Swiss study<sup>(3)</sup> 51% of the loggers surveyed reported chain saw exhaust-related health complaints, while in a similar investigation, 93% of 200 Swedish loggers surveyed reported frequent or occasional discomfort as a result of chain saw exhaust exposure.<sup>(5)</sup> Of 857 forestry workers surveyed in a German study, 91 complained of shortness of breath and 131 of tightness in the chest while operating their chain saws; of those, 9 had lost consciousness at least once.<sup>(9)</sup> Further common complaints included a (chesty) irritant cough, burning eyes, headache, nausea, and dizziness. Hagberg et al.<sup>(4)</sup> also found minor lung function changes due to exposure to chain saw exhaust.

Health problems appeared most often when air circulation was poor while the chain saw was in use. Most of the Swedish loggers reported health problems in deep snow (86%), thick forest stands (44%), and calm weather (39%). The German chain saw operators reported symptoms in coniferous forest twice as often as in the sparser deciduous stands.

To evaluate the exhaust exposure of chain saw operators under different conditions, amounts of exhaust inhalation were investigated by CO exposure measurements and biological monitoring of COHb. Environmental and working conditions influencing the CO exposure of the workers were studied by video recordings.

## SUBJECTS AND METHODS

This study was conducted during the summers of 1994 and 1995 and in the winter 1995-1996 in coniferous and deciduous forest stands. Locations were selected under the premise that extreme conditions in forest stand thickness and terrain should be avoided. Measurements were taken during the felling of trees as well as during the thinning out of stands. The meteorological conditions were recorded by noting wind speed and direction, temperature, and humidity. Output of cut wood and the duration of run cycles of the chain saws were reported every hour.

Two-stroke chain saws (Stihl Type 044C, Waiblingen, Germany and Husqvarna Type 242xp cat, Huskvarna, Sweden) equipped with catalytic converters were operated with a mixture of oil and gasoline in the ratio of 1:50. The lead-free gasolines used in the study (Motornix for Stihl and Aspen 2T for Husqvarna engines) are specially recommended by the manufacturers of the chain saws. A gas chromatography analysis showed both brands to be free of benzene, implying a probability of lower cancer risk for users in comparison with normal gasoline.

Fourteen chain saw operators volunteered for the studies; all were trained professional loggers (Table I). Twenty-two series of measurements on 11 subjects (10 nonsmokers and 1 smoker) were carried out during logging operations of spruces and beeches. While thinning out stands, 14 series of measurements on 7 subjects (6 nonsmokers and 1 smoker) were done. The daily profiles of COHb levels were measured during an 8-hour shift with a maximum interval of 1 hour between samplings. In addition, one sample each was taken before and after the shift. Capillary blood was drawn from the fingertip of each subject with heparinized capillaries and immediately analyzed in a Hemoximeter OSM 3 (Radiometer, Copenhagen, Denmark). The device was installed in a motor home equipped with temperature regulation and placed next to the forest stand under work.

TABLE I. Demographic Characterization of the Study Group

Demographic Characteristics	Means $\pm$ SD (n = 14)	Range (n = 14)
Age (years)	37.9 $\pm$ 11.7	22-59
Occupational experience (years)	17.8 $\pm$ 12.0	5-43
Weight (kg)	78.4 $\pm$ 6.9	68-90
Height (m)	1.74 $\pm$ 0.077	1.62-1.87

A mere 35  $\mu$ L of blood suffices for a set of analyses. The samples were hemolyzed ultrasonically in a glass cuvette at 40 kHz followed by photometric measurement at six different wavelengths to determine the following parameters: total hemoglobin (tHb), oxygen saturation of the hemoglobin by percentage (HbO<sub>2</sub>Sat), COHb content by percentage (COHb), methemoglobin content by percentage (MetHb), and oxygen content by volume-percentage (O<sub>2</sub>ct).

Each cycle of measuring and cleaning of the system took approximately 1 minute. At each sampling two capillary blood samples were drawn and the values from each averaged. The divergence between the samples was <0.2% COHb. To validate the test values, venous blood samples were taken together with the capillary blood samples at the end of the shift and examined by gas chromatography. The maximum deviation from the photometrically obtained results was  $\pm$ 0.4% COHb.

In addition, the CO concentration in the loggers breathing zone was recorded with a Compur Dositox gas warning system (Hartmann & Braun, Munich, Germany), which registered the CO concentration every 10 seconds by an electrochemical electrode.<sup>(11)</sup> The device was calibrated for a range from 1-500 ppm with a relative standard deviation (SD) <10%. The recorded values were stored in a small solid state memory (data logger) attached to the clothing of each subject and later printed out in protocol form by a personal computer system. The device proved to be sensitive to sudden jolts and bumps, which caused gaps to appear in most exposure measurements.

In a second series, video recordings (S-VHS system) were used to pinpoint the spatial expansion of the pollutants over time after emission from the exhaust pipe of the chain saw. By installing two cameras right-angled to each other, a three-dimensional image of the expansion of the exhaust cloud could be assembled. To make the exhaust more visible, 15% diesel fuel was added to the oil-gasoline mixture. To avoid damaging the catalysts, the platinum-coated monoliths were removed from the test chain saws. The diameter of the exhaust opening and the direction of emission were not altered in any way by this procedure. The chain saw operators were protected from pollutants of the exhaust by visor helmets fed by supplied fresh air.

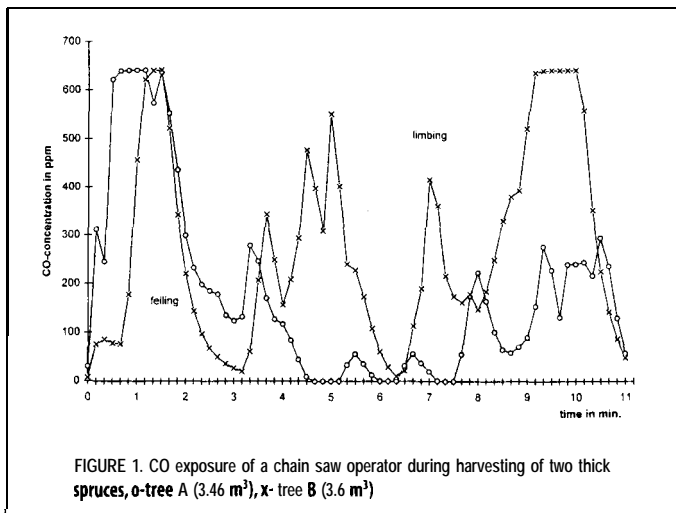
## RESULTS

The weather conditions during the experiment were not unusual, especially as there was no atmospheric inversion. The temperature in summer ranged from 11-23°C with humidity between 47 and 84%, in winter from -17 to 6°C with 21-99% humidity and a maximum snow layer of 0.2 m. Wind speeds were measured from 0-1.8 m/sec with an average wind speed of 0.4 m/sec. The chain saw was in operation for 22-60% of the working day; values over 50% were recorded only during the thinning out of young stands. During the course of the shift the operation time of the chain saws per hour fell visibly after 3 hours when workers were paid on a piecework basis. This resulted in reduced efficiency in the afternoon.

## CO Exposure Levels

The threshold limit value of 25 ppm for CO was repeatedly exceeded during the performance of all tasks. Occasionally the CO concentration climbed as high as 400 ppm during felling and limbing dense tops of coniferous trees. Maximum levels of >500 ppm were recorded in isolated cases. The highest maximum values for CO could not be measured exactly because the device's upper calibration limit of 500 ppm was exceeded.

Figure 1 shows the CO curves during the felling and limbing of two large spruces. Although both trees were felled on the same day in the same stand, one after the other, i.e., under basically identical conditions, the exposure of the chain saw operator differed greatly. While the exposure during the actual felling of the two trees is comparable, the inhalation during the limbing operation is significantly higher for the second tree because of its thicker crown.

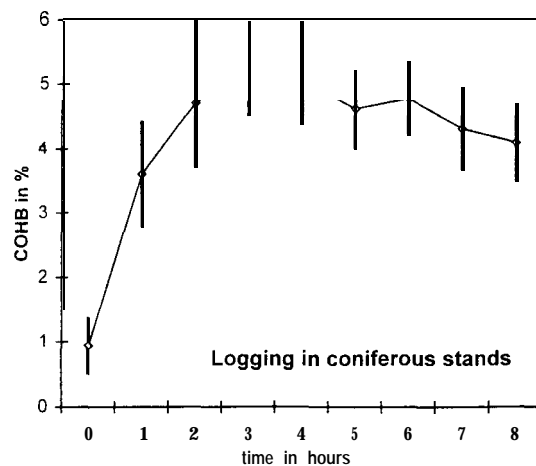


Due to the hard working conditions and the shock sensitivity of the device, some test values (an average of 14%, range 0.4–94.1%) in the measurement cycles were not recorded. Nevertheless, three complete cycles of CO measurements over an 8-hour shift were obtained. The first was taken in a spruce stand of medium thickness and revealed an 8-hour time-weighted average (TWA) CO concentration of 24.3 ppm; the second during thinning of a young coniferous stand, which gave a TWA value for CO exposure of 16.2 ppm; and the third, a TWA value of 23.7 ppm while logging beeches.

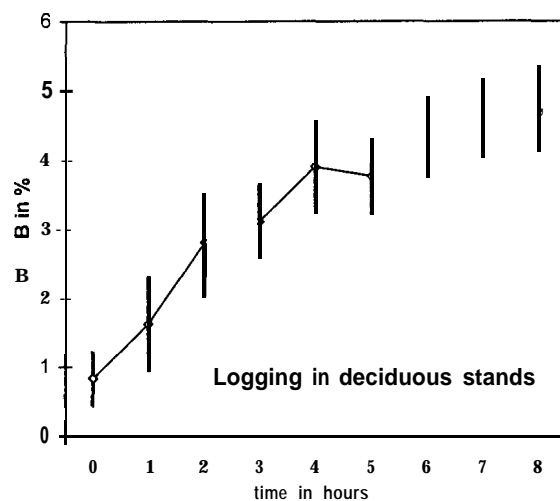
## COHb Concentrations

Figures 2 and 3 show means (SD of COHb daily profiles of non smoking loggers for two different tasks where the chain saw was used (logging of coniferous and deciduous trees). The maximum values were reached after 2–3 hours in coniferous stands under piecework conditions. As the shift continued, the COHb level slowly decreased until it was 20–30% lower than the maximum values at the end of the shift. The logging of beeches was done in a regular shift (no piecework), because some of the trees had to be pulled down by a radio controlled winch when caught in the branches of other trees.

Thinning out of coniferous and deciduous stands is shown in Figures 4 and 5. Daily profiles of the forestry workers are similar to those for logging spruces, but the COHb concentrations remain below the biological exposure index. The CO exposure in the stands of firs and spruces was slightly higher than in the sparser deciduous stands as proven by CO measurements, and higher COHb levels were also found in workers thinning out coniferous stands.



Two measurement cycles were run on the only smoker in the subject group. In the first cycle the initial concentration of COHb was 4.7%. This value increased to 6.5% after 2.5 hours of thinning out a young stand of spruces. The second cycle was taken during the harvesting of trees in dense forest. The COHb level rose from an initial concentration of 4.4% to 8.0% after 2.5 hours. In both cases, the subject had smoked one cigarette from the beginning of the shift until the maximum COHb value was measured.



## Video Recordings

Contrary to expectations, the hot exhaust was not immediately swept upwards by thermal lift, but remained close to the ground and floated away in the direction of the wind. This exposed all loggers performing tasks in a leaning or squatting position (especially felling) to greater amounts of exhaust. Furthermore, the distance between the exhaust pipe and the upper respiratory tract was reduced during the felling operation by the logger's squatting position and bent arms as he cut horizontally into the trunk. Because trees are usually cut down very close to the ground and

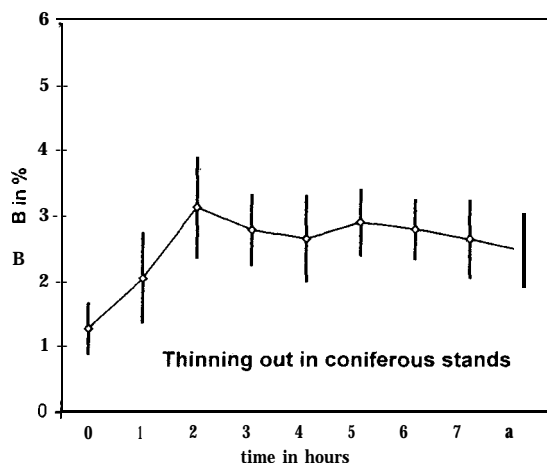


FIGURE 4. Thinning out in coniferous stands, means and SDs of COHb in six nonsmoking chain saw operators during an 8-hour shift

the exhaust pipe is pointed downward during this operation, the exhaust is deflected by the trunk, the roots, and the ground and directed towards the logger's respiratory tract. While the logger is bucking (cutting the fallen trunk into smaller lengths), there is again a partial deflection of the exhaust from the trunk.

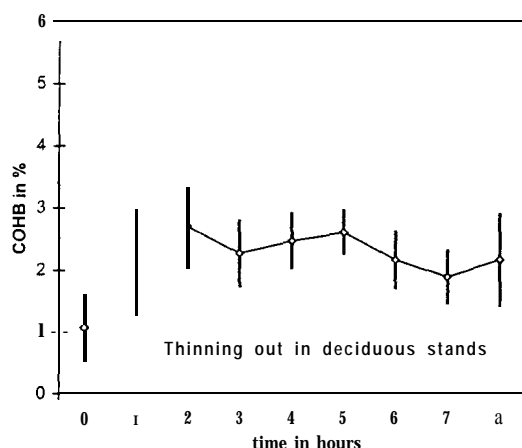


FIGURE 5. Thinning out in deciduous stands, means and SDs of COHb in six nonsmoking chain saw operators during an 8-hour shift

During the limbing of dead spruce branches, the exhaust cloud drifted away swiftly depending on the wind speed and direction. Where green branches were being cut, the exhaust accumulated from low to fairly high concentrations, depending on the thickness of the top. The logger moved into the cloud of exhaust while limbing. Above all, wide crowns with overhanging branches caused large amounts of exhaust to build up and be inhaled by the logger. Limbing the branches on the underside of the felled trunk must be done in a squatting or leaning position and consequently led to higher exhaust inhalation.

## DISCUSSION

The description of the relation between CO exposure and resulting COHb concentration is based on an equation in which a

mean level of physical exertion was assumed.<sup>(12)</sup> According to this formula a CO exposure of 30 ppm leads to a COHb of 5%. However, logging is extremely physically demanding. The correspondingly higher respiration rate increases the CO inhalation of the chain saw operators and leads to COHb values exceeding the biological tolerance value despite CO remaining below the maximum allowable workplace concentration in the air.

The efficiency of the forestry workers drops during the course of the shift, especially when paid on a piecework basis. The output of cut wood was 20–30% lower in the afternoon than in the morning. Therefore, the chain saws were not in use as often, which led to a lower exhaust exposure. Taking the biological half-life of COHb (approximately 5 hours) into consideration, it seems quite plausible that the COHb levels of the subjects would fall as the shift progressed. For this reason, taking blood samples only at the end of the shift is not always an appropriate method for determining maximum carboxyhemoglobinemia of chain saw operators.

In a Canadian study on five subjects, CO exposure was higher (up to 37 ppm) while COHb levels reached 3.4% only (one sampling just before noon) and were not correlated to exposure levels.<sup>(13)</sup> This may be because of the small number of subjects.

Coronary atherosclerosis often begins to develop in men before they turn 20, and for men above age 35, coronary heart disease is the most common cause of death. In randomized double-blind experiments an earlier onset and an increase of severity of stress-induced stenocardia in subjects suffering from coronary heart disease were observed after they were exposed to low COHb levels (<3%).<sup>(14,15)</sup> One of 10 asymptomatic persons manifested ischemic ST-segment depression.<sup>(7)</sup> The extreme physical demands on the loggers, paired with their COHb levels of up to 6%, could lead to the manifestation of coronary heart disease, which might otherwise remain latent. This would perhaps explain why more than 10% of the loggers in the German survey<sup>(4)</sup> complained of shortness of breath and more than 15% reported a tight feeling in the chest while working with the chain saw. Both symptoms are often observed during attacks of stenocardia. Eight percent of 1615 Swiss loggers had severe heart complaints while working with chain saws, and 23% had occasional symptoms.<sup>(16)</sup>

An increased thrombocyte aggregation as an effect of CO exposure<sup>(17)</sup> and a CO-dependent lipid metabolism disturbance<sup>(18)</sup> could be etiologically involved in the development of arteriosclerosis. A significant dose-dependent increase in the prevalence of angina pectoris was found among foundry workers exposed to CO.<sup>(19)</sup> Elevated standard mortality rates for coronary heart disease were recorded among New York City tunnel officers.<sup>(20)</sup> The CO concentration in the tunnel ranged from 30–40 ppm. In a Swedish study of 375 deceased loggers, an increased mortality rate was discovered for ischemic heart disease, cerebrovascular insults, and other vascular disorders.<sup>(21)</sup>

The above-mentioned potential link between CO exposure and heart and vascular disorders in loggers and other occupations indicates that additional attention should be placed on reduction of exposure as well as consideration of biological monitoring programs to estimate exposure.

## CONCLUSIONS

Exhaust exposure of chain saw operators was determined by personal air monitoring of CO and blood concentrations of COHb. Although very high short-term exposures occurred often, the CO

exposure over an entire work shift remained below the threshold limit value (25 ppm). Nevertheless, the biological exposure index for COHb was exceeded, because CO inhalation was elevated by forced ventilation from the high physical work load in the forest. Compared with CO in the inhaled air, COHb is the more valid parameter for determining the exhaust exposure of chain saw operators. In certain circumstances maximum COHb levels are reached after only 2-3 hours and then decline. Highest CO exposures were observed during operations in a leaning or squatting position leading to a shortened distance between the exhaust outlet of the chain saw and the upper respiratory tract of the workers. In addition, low wind speed and dense forest increased the exhaust inhalation. Avoiding exposure peaks described and analyzed in this investigation would lead to an effective reduction of exhaust inhalation by chain saw operators.

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